New Transportation Infrastructure Impact in Terms of Global Average Access - Intersection
"La Carola" Manizales (Colombia) Case Study

Diego Julián Perilla Ramírez
Universidad Nacional de Colombia, Departamento de Ingeniería Civil
Manizales, Colombia

Diego Alexander Escobar García
Universidad Nacional de Colombia, Departamento de Ingeniería Civil
Manizales, Colombia

Santiago Cardona Urrea
Universidad Nacional de Colombia, Departamento de Ingeniería Civil
Manizales, Colombia

Abstract

This study diagnoses the impact of the implementation of the “Carola” Intersection in global accessibility terms, establishing a comparative into mean travel time vectors, calculated from vehicle operational speed between the city of Manizales’ existing network and modified network including the new intersection, besides defining zones and users benefited by the new transport infrastructure.

Keywords: Global Average Accessibility, Geo-Statistics, Road Network, Case study

1 Introduction

The Manizales municipality (414,906 residents in the metropolitan area), is located
in the department of Caldas at $5^\circ03'58''\text{N}$ and $75^\circ29'05''\text{W}$ in the Greenwich meridian over the Central mountain range at 2150 MASL, near the “Nevado del Ruiz”, as a part of the Colombian gold triangle (see Figure 1).

The administration of the city of Manizales has sought to be consistent with the national government’s purpose to consolidate transport infrastructure as one of the most important for economic growth [19] through the execution of high-impact projects. Manizales has been characterized for promoting projects of great impact for mobility, such as the intersection of Fuente, inaugurated at the beginning of 2017, strengthening the transit of the Panamericana highway, as well as the transit of users on their trips to Bogotá or Medellín [20]. Other type of projects with similar characteristics are being executed in key points for mobility during peak hours, i.e. the Intersection San Marcel in charge of the National Institute of Roads and the Carola intersection in charge of the Mayorship of Manizales.

The Carola intersection is established within the current Manizales Development Plan (2016-2019), proposed in the Physical-Spatial dimension, and framed as a safe, effective and sustainable road infrastructure, transit and transport project, with the purpose of making mobility efficient, safe and environmentally compatible [19]. The reason why the research is developed in terms of global average accessibility is to evaluate the impact that this infrastructure would have on the average travel times and the new spatial coverage in relation to the current situation.
A literary review, a description of the research methodology, discussion on data and results, as well as a review of the main conclusions, follow this paper’s introduction.

2 Literature Review

The concept of accessibility has been frequently used in territory planning and in transport analysis during the last fifty years. There are records of its use since the last century in the 1920s. North America was a pioneer in its use associated with transport networks and travel distribution patterns [2]. However, the most classic definition of this term was proposed by Hansen in his article "How Accessibility Shapes Land Uses" published in 1959 where accessibility is defined as "The potential of opportunities for interaction", also laying the first mathematical bases of the model. On the other hand, in 1976, Weibull developed an axiomatic approach for territorial accessibility models, making a meticulous mathematical analysis of the previously proposed models [7, 16, 18, 26].

Accessibility measures have been classified in different ways over time, according to study purposes, scope and data availability, which would determine its accuracy [11]. Generally, the literature defines three types of accessibility: relative, integral average and global average. Relative accessibility is the measure between two points of the transport network considering distance or time [18]. Integral average accessibility refers to different types such as: accumulated opportunities [3, 18], impedance function [1, 9] and utility as a measure of the economic potential of a city [5, 11]. Global average accessibility results from the average travel time between all nodes or zones of an infrastructure network, and is used to determine network infrastructure quality through average operating speeds and their directionality [8]. In the literature, global average accessibility was proposed by Geurs in 2001, who considered accessibility as a measure of infrastructure. Furthermore, accessibility calculations can take different perspectives and different factors can be used to enrich the analysis such as: travel mode, purpose of travel, age, gender, socioeconomic groups, among many others [22].

Accessibility measures have been used for decades by researchers to analyze related topics such as: urban development planning and land use [12], public transport analysis [14], equity and social exclusion in transport [24], sustainable transport development [6], access to health systems [9], economic development [17], social cohesion [10], provision and location of services [4], road addressing [8], among many other studies.

3 Methodology

The methodology of the study is based on the development of four consecutive stages shown in Figure 2 with their description enunciated below.
3.1 Verification and adjustment of the transport infrastructure network of Manizales

Geo-referenced information was taken from the network of Manizales, updated with recent infrastructure changes. Software using geographic information systems (GIS) with coordinates data of node location, arc lengths ($L_a$) and information on operating speeds ($V_{prom}$), which were taken from official reports such as the Mobility Plan of Manizales in 2017 [23], were used.

3.2 Existing network modification with the implementation of new transport infrastructure

Based on the existing road network and the geometric design of the new intersection (Figure 3), the transport infrastructure network is modified by creating the nodes and arcs necessary for their representation, also changing address attributes, arc length and expected operating speed according to the design. Prior to the calculation of the global average accessibility, the updated network is reviewed and evaluated, verifying the topology between nodes and graph, including the works executed in the last year. The new intersection gives continuity to the traffic on the Kevin Angel Avenue that connects the city from East to West, eliminating the existing traffic signal and increasing the average operation speed to 50 Km/h on said corridor.
3.3 Calculation of global average accessibility

The matrix of minimum times between all network nodes is calculated with the information obtained from the existent and modified networks in previous stages, based on the travel time of each arc; the minimum travel time \( t_{vi} \) between each node is measured with the Dijkstra algorithm; and, finally, the average travel time \( T_{vi} \) (Expression 1) is determined. [27]. The vector of travel time obtained is related to the geographic coordinates of each of the nodes obtaining the matrix from which the isochronous curves of average travel time are generated.

\[
\overline{T_{vi}} = \frac{\sum_{j=1}^{n} t_{vi}}{n-1}, \quad i = 1, 2, 3, \ldots, n; j = 1, 2, 3, \ldots, n
\]  

(1)

For the geostatistical calculations, the ordinary Kriging Method with linear semivariogram was used as a prediction model of the average travel times. The semivariogram characterizes the properties of spatial dependence between points belonging to an observed sample, which is calculated by Expression (2) [13], where \( Z(x) \) = value of the variable in a site with x, y coordinates; \( Z(x+h) \) = another sample value separated by a distance h; \( n \) = number of couples that are separated by that distance. It is emphasized that, at a lower distance, the similarity or spatial correlation between the observations is greater.

\[
\overline{Y(h)} = \frac{\sum(Z(x+h) - Z(x))^2}{2n}
\]  

(2)

The ordinary Kriging method proposes that variable value can be predicted as a linear combination of the \( n \) random variables, as presented in Expression (3) [13], where \( \lambda_i \) = the weights of the original values. This method has been used for different studies related to the prediction of supply models in transport networks [25].

\[
Z_{(x0)} = \lambda_1 Z_{(x1)} + \lambda_2 Z_{(x2)} + \lambda_3 Z_{(x3)} + \lambda_4 Z_{(x4)} + \ldots + \lambda_n Z_{(xn)} = \sum_{i=1}^{n} \lambda_i Z_{(xi)}
\]  

(3)
In order to establish the relationship between the isochronous accessibility curves and the population of the city, the neighborhood division map of the city of Manizales, which has information on areas, densities and socioeconomic strata, will be used. It is possible to establish the percentage of the population that will have the greatest reduction in travel times given the construction of the new transport infrastructure.

3.4 Calculation of the variation gradient of travel times

Based on the calculation of the global average accessibility of the existing network (AMGa) and the modified network (AMGf) of the city of Manizales and the use of software tools (GIS), the gradient percentage variation of travel time in each point of the network (see Expression 4) is determined (% Gvar). The result will be a map evidencing the estimated variation in average trip times with the implementation of the new intersection La Carola.

\[
\text{% Gvar} = \left( \frac{\text{AMGa} - \text{AMGf}}{\text{AMGa}} \right) \times 100
\]

4 Results and discussion

4.1 Global average accessibility in its current scenario, year 2017

The results of the geostatistical calculations, represented by isochronous curves in ranges of every 5 minutes (See Figure 4), show that the city is covered with average travel times of between 20 and 65 minutes. It is worth to highlight that the isochronous curves found between 20 and 35 minutes of average travel time covers 86% of the total study population (358,269 inhabitants).

Isochronous curves between 20 and 25 minutes cover 15% of the study area and are located in the downtown area (Central Bussiness District - CBD) and areas adjacent to the two main arterial roads that connect the city, which are Kevin Angel Avenue and Santander Avenue.

In contrast, the curves showing the highest average travel times are found in the peripheries of the city: the 55-minute curves cover the Maltería and Gallinazo sectors east of the city and within the same curve to the southwest of the city are the sectors of Bajo Tablazo and Villamaría, as shown in the boxes of Figure 4. The area with the least favorable average travel times are located northwest of the city in the sector of La Linda with curves greater than 60 minutes.
4.2 Global average accessibility future scenario, including La Carola intersection

Once the global average accessibility with the modified network was estimated, isochronous curves were obtained in the same ranges of accessibility calculation made in the existing network; between 20 and 65 minutes, but with noticeable changes mainly in the curve of 20 to 25 minutes, area that increases significantly. Figure 5 shows the results of the global average accessibility calculation to the network in the future scenario. The reduction of average travel times is more noticeable on Kevin Angel Avenue, this corridor communicates the city from East to West. This change is shown in detail in the red box, which also shows the modification to the existing network with the start of operation of the new intersection.

4.3 Global average accessibility gradient

Figure 6 shows the gradient curves of the areas where an increase or savings in the average travel time will take place, measured as a percentage of change between the current and future scenario. It is evident that some areas of the periphery, such as the La Linda sector (northeast), had savings between 5% and 10% in the average travel times. Sectors close to the intersection are observed with savings of up to 30% (see Fig. 6). Likewise, there is a small increase in the average travel time in certain sectors of the La Carola neighborhood (next to the intervention).
This is due to the fact that the average travel time is directly related to the length of the arches. However, this means that users, despite having more mobility options in the sector, will have to travel longer lengths, but without representing disturbances due to traffic or waiting times for turns at intersections.
Figure 7 shows the saving percentage and its effect on the population. Up to 8% perceive savings between 5% and 10% of their mean travel times, which equals to 5000 families favored in the city. Moreover, up to 6% of the population obtain savings of 15%. Finally, it should be noted that 2% of the population receives savings in their average travel times of up to 20%, which indicates that this road infrastructure alternative will benefit a large number of inhabitants.

![Graph showing covered population per saving percentage of travel time](image)

**Fig.7:** Covered Population per saving percentage of travel time. Source: Authors.

With information obtained from the accessibility calculations in the average travel time matrix, it is possible to classify the covered population into socioeconomic strata. This classification consists of assigning a category from 1 to 6 to the areas depending on dwellings conditions, access to basic services and income per family, 1 indicating the lowest and 6, the highest. Figures 8 and 9 show the variation between the current situation and the future one by socioeconomic stratum. As can be seen, the most benefited stratum 5, located in close proximity to the curve whose average travel time is close to 30 minutes for about 99% of the population of the same stratum.

### 5 Conclusions

The methodology used to calculate global average accessibility can also be used in developing countries and intermediate cities with similar contexts, allowing to determine the impacts that new infrastructure works can generate.

The impact generated with the implementation of the new intersection mainly covers Kevin Angel Avenue. Coverage percentage of the 25-minute curve increases from 5.15% to 5.71% and the 30-minute curve of 28.10 % to 29.90%, decreasing the average travel times for Laureles, Los Rosales and La Leonora neighborhoods, with socioeconomic strata 4-5.
According to the analysis, 7.2% of the population save from 5% up to 25% in their mean travel times, which translates into a benefit to a considerably large group in the city.

**Acknowledgements.** The authors thank the research center of sustainable mobility of the National University of Colombia, campus Manizales.
References


New transportation infrastructure impact


Received: January 20, 2018; Published: February 27, 2018